The Host-Flea Relationships in a Sylvatic Plague Endemic Region of the Southwestern United States, with Special Studies on some New Approaches to Plague Control

By

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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DEDICATION

To my wife, Anita

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Major Department: Entomology and Nematology

Host-flea relationships were studied from March 13, through July 16, 1968, on a field plot at Red Bluff Ranch, New Mexico. Data on host abundance, occurrence of male versus female animals, and a population estimate were given, and their relationship to plague discussed. Trapping efficiencies of the two live traps used during the study were determined. Total flea indices, and indices for individual flea species by animal host were given. A laboratory study was conducted at the U.S. Department of Agriculture's Insects Affecting Man and Animals Laboratory, Gainesville, Florida, 1970-1971. A potential method for controlling fleas on wild animals was evaluated, and other possible solutions to flea control during plague epizootics were discussed.

Nine animal species, totaling 306 animals and representing 203 captures and recaptures, were collected during the

study. Dipodomys merriami Mearns, was the predominant animal on the study site, it represented 30 percent of the total animals trapped. National (Tomahawk) traps were found more efficient for trapping animals on the study site than Sherman traps. Exceptions were the very small animals that could slip through the wire sides of the National trap.

Flea indices were determined graphically and in Table form to show the variation in the two methods. Advantages and disadvantages of the two methods were discussed. Flea indices generally declined during the period of study.

A vaseline-fenthion mixture was used in an attempt to develop a new approach to flea control on wild animals. The material was placed in artificial rat runs with a bait in the center of the run. To reach the bait the rat would have to pass through the sticky mixture. It would then lick its feet, the material would be taken internally, act as a systemic insecticide, and kill the fleas placed on the rats. The method was not considered a practical flea control measure.

INTRODUCTION

The plague bacillus, Pasteurella (Yersinia) pestis (Lehman and Neumann), (Herms 1961) has been a scourge to mankind since time immemorial. We are fortunate today, with our high standard of living and scientific knowledge to have this disease for the most part, under control. Even now, under these conditions, we find the disease getting out of hand for short periods of time in various parts of the world. India, over the past 20 years has experienced epidemics of considerable magnitude (Pollitzer 1954). More recently and extending to the present, we find South Vietnam an area with a present plague problem of considerable dimension. In 1966, an estimated 5,000 cases occurred in the indigenous population, but less than 10 cases were reported among United States (U.S.) military personnel in the area, although in many cases they were in close contact with the civilian population. It has been surmised that the routine immunization given U.S. personnel entering the area has been effective in preventing plague from this susceptible population (Cavanaugh 1967).

This disease has never been a major problem in the United States, although periodic cases have occurred in seaport cities both on the east and west coasts. These cases were considered ship-borne plague, i.e., plague brought into the

U.S. by infected rats and/or fleas, (Kartman et al. 1967). This type of plague is non-existent in the U.S. today, but the potential still exists, especially from the U.S. retrograde movement out of South Vietnam.

The primary focus of plague in the U.S. today is in epizootic form. Since McCoy, in 1908 (as cited by Kartman, 1970) discovered plague in the California ground squirrel, Spermophilus (Citellus) beecheyi (Richardson), the disease has moved eastward as far as the western portions of Texas, Oklahoma and Kansas. Numerous animals, primarily wild rodents and lagomorphs (rabbits) have been found to harbor the disease. In addition, many of the flea species of these animals have been found infected.

Government organizations, principally the U.S. Public Health Service and local state health agencies, have been following the disease for a number of years. In the last few years the U.S. Army, due to the situation in South Vietnam, has sponsored research on plague ecology and control.

At the present time, studies, on the basic ecological relationships of the hosts and their fleas, and the control of these fleas, are being conducted by the New Mexico, Environmental Improvement Agency (formerly New Mexico Health and Social Services Department). The studies are being financed by the U.S. Army Medical Research and Development Command. In addition, cooperative studies on flea control, with systemic insecticides plus certain new control approaches,

are being evaluated jointly by the U.S. Department of Agriculture, Entomology Research Division, Insects Affecting Man and Animals Research Laboratory, Gainesville, Florida, and the New Mexico, Environmental Improvement Agency.

The field studies were conducted in southeastern New Mexico where known human and zootic plague had been previously recorded, (Kartman 1960). The New Mexico Environmental Improvement Agency had done previous work in the area, and had shown suitable animal and flea population were present to conduct the type of study desired. (Rael et al. 1969).

To control any arthropod-borne disease the classic method of breaking the transmission cycles is either at the host or vector level. Plague is no exception to this rule. In South Vietnam, immunization appears the most practical and seemingly effective method. When plague is in a zootic form such as the western U.S., this approach is not possible. The most practical control method seems to be control of the insect vector or the reservoir animal.

The purpose of this research was: to study the basic biology of the wild animals and their fleas associated with plague, and to evaluate some new control approaches for future studies in plague control. The latter experiments were conducted at the U.S.D.A. Laboratory in Gainesville, Florida.

REVIEW OF THE LITERATURE

This work, though not directly involved as a plague study, was done to provide basic background material for future ecological studies in plague control operations. Because of the volumous material written on all facets of plague over the years, no attempt will be made to review the literature completely. However, a brief resume of plague, beginning at a world level and terminating in areas related to the field of study is given.

Plague - A Brief History

Plague, according to Wu Lien-teh et al. (1936) and cited by Pollitzer (1954), has been present since time immemorial in the areas within or near the central Asiatic plateau. This area is considered the original home of the infection. Wu Lien-teh further states the first plague epidemic on record was the outbreak among the Philistines in 1320 BC. This is described in the Bible in I Samuel V and VI. Pollitzer (1954) reports that some writers refute this date due to interpretations of the Biblical text and further states the first really satisfactory evidence regarding the prevalence of plague concerns a pandemic that occured in Pelusium in lower Egypt in 542 A.D. This outbreak, which lasted approximately sixty years, spread as far as Constantinople

and killed an estimated 100 million people.

Probably the most well-known epidemic as far as modern man's historical record is concerned was during the Middle Ages, when the "Black Death" (plague) killed 25 million in Europe (Herms 1961).

A more recent epidemic occured in Hong Kong in 1894 and spread to many world ports via shipping lanes (Pollitzer 1954). According to Herms (1961), rats, infested by rat fleas, and transported in goods, are the chief disseminators of the disease.

From 1900 to 1952, plague was recorded in 39 countries, and from 1945 to 1952, there were 37 cases reported from seaports of various countries (Atlas of Plague, 1952).

Today the largest focus of plague in the world is in South Vietnam. In 1966 there were approximately 5,000 reported cases (Cavanaugh et al. 1967). Strict quarantine measures seemed to have contained the disease in that country (Rust et al. 1969).

Plague was first recorded in the United States from San Francisco in 1900 (Jellison 1959). The outbreak ended in 1904, but reappeared in 1907. Other cases occurred in Seattle in 1907, New Orleans in 1912, several Gulf coast cities in 1920 and Los Angeles in 1924.

Plague - Western United States and Canada

Sylvatic, or wild rodent plague as it is called by many workers, is endemic throughout the western United States, and in the provinces of Alberta and Saskatchewan, Canada

(Linkfield 1966). Various workers have reported on plague in the western United States. McCoy (1910), in 1908, first discovered plague was no longer confined to rats and rat fleas in the United States as it had spread to the wild rodents and their fleas in the San Francisco Bay area. Eskey and Haas (1940) reported the primary reservoirs of plague were ground squirrels, Spermophilus (Citellus) spp.; woodrats, Neotoma spp.; and prairie dogs, Cynomys spp.

Today, according to Kartman (1970), there are 10 rodent and 2 lagomorpha (rabbit) genera, that include 45 species, found important in the ecology of sylvatic plague.

In New Mexico (where this field study stook place) plague organisms have been recovered from wild rodents, rabbits, and hares and/or their fleas, in 23 of New Mexico's 32 counties (Rael et al. 1969). Further documentation of the study site as a potential plague area is given by Kartman (1960), who reported that two hunters contracted the disease by handling diseased rabbits they had shot. These cases occurred approximately eight kilometers north of the study site selected for this research and contains similar topography, flora, and fauna.

Plague Epidemiology

Kartman (1970) lists three main situations which lead to the rise and dissemination of plague. He states that wars are a primary factor in the spread of the disease, especially the wars of the 18th and 19th centuries where troops were involved as both victims and agents of dissem-

ination. Further, Kartman reports, the unusual exacerbation of plague incidence in Southeast Asia, especially in Vietnam, should be examined carefully from the epidemiological standpoint as a basis for a reevaluation of the plague problem in specific countries of the world. Another type of epidemiological situation illustrated by Kartman includes those endemic and enzootic regions where the great mass of the people live in a condition of extreme poverty. He cites the recent plague epidemics in Bolivia (1964-1965), Nepal (1967), Java (1967-1968), and the prolonged cycle of epidemics in southern India as examples.

His third category is that found in more affluent societies, or in countries that have reached a stage where they can effectively organize a public health service. In these circumstances rat-borne plague tends to disappear and sporadic plague cases are due to the occasional transmission of the infection when people invade a nidus of sylvatic plague.

An excellent review of plague epidemiology is given by Pollitzer (1954); he covers most of the significant plague epidemiological work up to that date. The World Health Organization (WHO) publication/Vector Control/66.217.1966 gives a more recent report on plague epidemiology, including sections on plague associated rodents and rodent ectoparasites. A brief, but informative survey of plague epidemiology is made by Starke et al. (1966).

The plague situation in the United States, falls into Kartman's third category. He states 120 human cases occurred

in the United States from 1908 to 1968, that were directly attributed to wild rodents, rabbits, and/or their fleas. Of these, New Mexico has had 20 cases. Since 1966, each case has been well documented, either by the New Mexico Environmental Improvement Agency, Vector Control Unit, (Miller 1971) or the U.S. Public Health Service (Kartman, 1970).

Host-flea Relationships

Many workers have created countless publications on the Siphonaptera. No attempt will be made to review all the literature on this subject. A general description of the Siphonaptera is given by Matheson (1950). Snodgrass (1946) presents a very comprehensive review on the skeletal anatomy of fleas. Probably the most complete work on Siphonaptera taxonomy was done by Hopkins and Rothschold (1953) (1956) (1962). Stark (1959) presents an excellent study of many of the western fleas in his book The Siphonaptera of Utah. The most complete, but rather outdated book on western fleas was written by Hubbard (1947). Wheeler et al. (1971) have prepared a taxonomic key to the fleas of New Mexico and is now in manuscript. In addition, Wheeler (1968) developed a working taxonomic key specific to the fleas of Red Bluff Ranch, which includes all the fleas in this study, plus other species that the New Mexico Environment Improvement Agency collected during their ecological and flea control studies in the area.

Biology

Various workers have studied the life history of fleas.

Bacot's (1914) classic work with Pulex irritans Linneaus remains one of the basic guides to life history studies. Most of the research in flea biology has been done with Xenopsylla cheopis, Rothschild. This is due to its association with plague and, in addition, it is one of the easier fleas to rear in the laboratory. This species was used for all the laboratory work done in this study. Most of the following comments deal with X. cheopis. Note will be made if any other species are involved.

Buxton (1948) concluded the adult flea could survive at temperatures from 24-32°C and the life cycle of the flea will vary according to the temperature and humidity. Hopkins (1935) reported that the life cycle could be completed in about 56-63 days, the minimum being 42 days, at a temperature of 20°C and a relative humidity of 100 percent. Krishnamarthy et al. (1963) found that at a temperature between 25-28°C, and a relative humidity between 75-80 percent, the life cycle could be completed in 24-29 days. Studies made by Burroughs (1953) indicated that six species of fleas infesting rodents in the western United States had maximal periods of survival comparable to X. cheopis.

Rearing

Fleas utilized in the laboratory portion of the study were provided by the U.S. Department of Agriculture, Insects Affecting Man Branch and Animals Branch, Gainesville, Florida. They were reared by the technique described by Cole et al. (1972). No fleas from the study area in New Mexico were reared.

Flea Relationships

Numerous workers have collected fleas and their host for taxonomic or distribution studies; Hirst (1923) was the first to study the relationships between the flea and the host. He demonstrated that in addition to X. cheopis, two other Xenopsylla spp., namely X. astia Rothschild and X. brasiliensis (Baker) were present on the rats he collected. It led the way for further work on plague-vector studies. Taylor and Chitre (1923), as cited by Pollitzer (1954), confirmed Hirst's findings and showed that although X. astia is capable of becoming blacked and transmitting plague, it is a markedly less efficient vector than X. cheopis or X. brasiliensis.

Flea Surveys

Before appreciating the influence exerted on the transmission of plague by variations in the incidence of the vector fleas, it is necessary to consider the methods recommended for flea surveys.

Cole and Koepke (1947) give an excellent guide for all workers to follow. It states:

> 1. Indices computed from total fleas are unreliable because they are apt to include non-vectors. as well as species which are unequally effective as vectors.
>
> 2. The time fleas of different species spend on their hosts is apt to vary considerably.
>
> 3. No reliable measurements of the absolute number of the fleas can be made without considering the number of rodents because "a decreasing host population will reduce the average counts".

4. The host species ought to be uniform in compared samples because, as in the case of R. norvegicus and R. rattus, for instance, different rodent-species show differences in flea infestation.

5. The age, as well as the size, of the individuals affects the counts, young and old rodents being liable to heavy infestation. The same may hold true of unhealthy animals.

6. Trapping techniques must be consistent in order to obtain comparable data.

7. Widely different indices may be obtained from rodents trapped in different sections of a town, or in different locations within one particular neighbourhood, or even on different levels of one building. X. cheopis, for instance, particularly infests rats in grain stores, and is markedly more abundant on rodents trapped inside buildings than on those caught outdoors.

8. Fleas do not uniformly infest all rodents of a locality, but show a patchy distribution so that, sometimes, a large part of a flea population is concentrated on a few animals.

Other workers (Pollitzer 1954) believed that instead of indices, more reliable results can be obtained in flea surveys by computing the percentage incidence of the various species or the infestation rates, i.e., the percentages of rodents infested with the various flea species.

Workers such as Macchiavello (1950) have recommended that the total or "absolute" flea index should be determined by considering the results of examination of the burrows and nests, as well as those of surveys carried out in the usual manner. He recommends the application of the formula: $AFI = \frac{RF + NF}{TR}$, when AFI stands for the absolute flea index, RF for the total flea population living on the rodents, NF for the absolute number of fleas from flea breeding or flea

harborage, and IR for the total rat population of the area concerned.

Pollitzer (1954) states that desirable as determinations of the absolute flea indices by this or other methods are, it seems difficult if not impossible to make routine use of such procedures.

A recent study (Mitchell 1971) in India, utilizes the graphic method of comparing flea indices with total number of animals infested. Though not as accurate as some formulas presented by earlier workers, it appears to be a practical and relatively simple method of showing trends in host-flea relationships.

In New Mexico, Rael et al. (1969), using an ecological approach to host-flea relationships, discuss these associations by frequency of fleas on a particular host and percent occurrence of the flea on the host.

There is no one-and-only guide that can be given to the study of the host-flea relationships of plague. What might work in one area may not be feasible or practical in another area. Kartman (1970) ably describes the status of this work in the United States by stating:

> It is important to indicate that oecological studies of mammals involved in plague in the United States have only scratched the surface of that formidable epizootieologic complex represented by the phrase "wild rodent plague". We need intensive and long-term studies of mammalian oecology specifically within the environs of plague localizations or nidi.

Animal Relationships

Identification--Hall and Kelson (1959) present one of the best reviews of mammalogy available for definitive taxonomic work. An earlier, but valuable book for the student of mammal taxonomy is a check list of North American Mammals by Miller and Rahn (1901). For the basic identification of mammals needed for this study a field guide by Burt and Grossenheider (1964) was found adequate.

Ecology--One of the primary objectives of this work was to study the host-flea relationships of the animals on the study site. An excellent presentation of desert animals by Miller and Stebbins (1964) gave an insight into the habits of the animals under scrutiny.

Microclimate--Kennerly (1964) conducted a study on the microenvironment of pocket gophers, and tested some instrumentation not before used by the field ecologists. Haas (1965) did a similar study but created artificial burrows for his work. Another paper dealing with microclimates was done by Mitchell (1971). He simulated burrows of Bandicota bengalensis in India. His work, though well documented, seems to conflict with results of earlier workers.

Populations--One of the most widely utilized techniques for determining animals populations was devised by Schnabel (1938). In studies that have large numbers of captures and recaptures the method is very accurate but when small numbers of recaptures occur, it results in a large standard error. Wildlife workers have devised numerous census

methods for estimating animal populations. Many of these are discussed by Mosby (1963). A number of these techniques are statistically feasible but have such large confidence limits they are not practical.

Laboratory Studies

Numerous papers have been published on various aspects of flea control. Because this paper deals with just one method, control through the systemic route, only brief mention will be made of the more conventional techniques.

Metcalf et al. (1962) and Herms (1961) give basic flea control procedures including recommendations of insecticides to use. Pollitzer (1954). gives an excellent summary of flea control as applied to plague control operations. Most of his recommendations deal with DDT, which has now been replaced by newer materials. A list of insecticides effective against the oriental rat flea is given by Burden (1966).

Most of the work to date has been done on domestic rodents and their fleas. A few papers have been presented on control of fleas on field rodents. Ryckman et al. (1953) evaluated four compounds including DDT for control of wild rodent fleas of the California ground squirrel. All the compounds were found effective in laboratory tests (Smith 1951). Ryckman also tested various application methods, including spraying the surface, dusting the surface and spraying individual burrows. Of these applications only the latter produced significant reductions in flea indices.

Miles and Wilcomb (1953) working in west Texas with DDT found that the broadcast method of application was not effective in reducing flea populations on pack rats (Neotoma micropus Baird). Miller et al. (1970) working on the New Mexico ranch site used in this dissertation evaluated five insecticides under field conditions. None of the chemicals gave satisfactory control though two of the chemicals showed some initial reduction in flea indices. All the materials had been shown effective in laboratory screening tests (Burden 1966). The problem of sucessfully controlling fleas on wild rodents and lagomorphs seems to be a problem of application method rather than effective insecticide.

A new approach to this application problem has taken the form of systemic insecticides. This concept, though new as far as the flea control on wild animals is concerned, has been around for a number of years. Parman et al. (1928) administered unsuccessfully, oral doses of chemical compounds to poultry to determine systemic insecticidal activity.

One of the first successful attempts at systemic control was reported by Lindquist et al. (1944) who showed that the bed bug, Cimex lecturlarius L., could be killed when fed on rabbits that had been given oral doses of DDT and pyrethrum. DeMeillen (1946) found that the bed bug, the yellow-fever mosquito, Aedes aegypti (L.), and a tick, Ornithodoros moubata (Murray), either died or showed toxic effects after feeding on rabbits that had been fed BHC. Knipling et al. (1948) fed 33 chemicals to rabbits to test their effectiveness

on bed bugs. Only indandione compounds caused complete mortality. Eddy et al. (1954) demonstrated that populations of the yellow-fever mosquito, the stable fly, Stomoxys calcitrans (L.), and the horn fly, Haematobia irritans (L.) were reduced when allowed to feed upon cattle receiving lindane. Larvae of the stable fly, horn fly, and house fly Musca domestica (L.), were killed in the droppings of livestock fed aldrin and dieldrin. Adkins et al. (1955) found Trichlorofon to be the best of 13 compounds for bed bugs and nymphs of the lone star tick, Amblyomma americanum (L.). Drummond (1958) found three organic phosphorous compounds to be effective against screwworms on sheep and goats, and one effective against stable flies and ticks. Systemic insecticides have been widely used for control of cattle grubs, Hypoderma lineatum (de Villers) and H. bovis (L.) Harvey (1960) tested the systemic activity of several compounds against the oriental rat flea, Xenopsylla cheopis (Rothschild). In small scale experiments, Bennington (1960) found that 6 g of ronnel-cornmeal mixture killed all fleas in 3 days. Hill et al. (1963) evaluated 21 compounds for systemic activity for control of the oriental rat flea on white rats. None of the 21 compounds produced more than 50 percent mortality of the fleas. Five compounds were considered worthy of more extensive study. All these compounds caused 80 to 100 percent mortality up to twenty hours.

Clark and Cole (1968) found that four systemic insecticides incorporated into the diet of hooded white rats produced 100

percent mortality in the oriental rat flea. Further work by Clark et al. (1971) showed that three insecticides, fenthion, mirex, and diazinon, successfully controled wild caught fleas of cotton rats, Sigmodon hispidus (Baird), Kangaroo rats, Dipodomys spectabilis Merriam, and the cottontail rabbit, Sylvilagus audubonji Nelson. Present studies are underway to further test the applicability of systemic insecticide baits to control wild animals fleas.

MATERIAL AND METHODS

Location and Description of Field Study Area

A permanent study site was established at Red Bluff Ranch, a cattle ranch located approximately 48 km north of Roswell, New Mexico. This region lies within the lower Sonoran life zone (desert biome) at an elevation approximately 1158-1239 m. A series of bluffs from where the name Red Bluff originated, transects the western quarter of the ranch from north to south. The bluffs divide the ranch into a western and eastern plain, the latter sloping into the Pecos river. The southeastern section of the ranch contains several, usually dry, lake beds. The location of the study site was in the southeastern section of the ranch. The area was chosen because it typified the flora and fauna of the ranch.

Climate--The climate is semi-arid in nature. The average minimum, 6.7°C, occurs in late December or early January. The average mean temperature is 15°C. Total annual precipitation is 29.4 cm, over half (17.8cm-21.6 cm) occurs as rainfall from June through September. Though snow occurs in the winter season, little precipitation of any kind normally occurs from January through April.

Flora--The ranch has several floral associations. These are influenced somewhat by topography and overgrazing.

Mesquite, Prosopis juliflora Wats, is dominant on most of the valley floors and slopes while the creosote brush, Larrea tridentata Vail, occurs on many of the ridges. The predominant tree on the ranch is salt cedar, Tamarix gallica Linneaeus; this occurs only along natural drainages and in dry lake beds. Predominant grasses are Bouteloua sp. and Hilaria sp. These comprise the main diet of the cattle grazing on the ranch.

Fauna--Numerous rodent species abound throughout the ranch. Eight species were collected on the study site itself. These will be named in the next section. Rabbits (Lagomorpha), are abundant in the area and include the black-tailed jackrabbit, Lepus californicus Gray, and the desert cottontail, Sylvilagus audubonii (Baird).

Carnivores inhabiting the area include the coyote, Canis latrans Say; gray fox, Urocyon cinereoargenteus (Schreber); kit fox, Vulpes velox (Say); striped skunk, Mephitis mephitis (Shaw); badger, Taxidea taxus (Schreber); and the bobcat, Lynx rufus (Guldenstaedt).

Predatory birds abundant in the winter are the marsh hawk, Circus cyaneus (Linnaeus), and red-tailed hawk, Buteo jamaicensis Bangs. In the summer months the burrowing owl, Speotyto cunicularia Ridgway, and Swainson's hawk, Buteo swainsoni Bonaparte, are common. The most common reptile that inhabits the area is the western diamondback rattlesnake, Crotalus atrox Baird and Girard; other snakes observed include the prairie rattlesnake, Crotalus viridis

(Rafinesque), the coachwhip, Masticophis flagellus Shaw; the bullsnake, Pituophis catenifer (Daudin); and the hog-nosed snake, Heterodon nasicus Baird and Girard.

Other than the ranch cattle, the hoofed animals present include the pronghorn antelope, Antilocapra americanum (Ord) and the mule deer, Odocoileus hemionus (Rafinesque).

Selection and preparation of study site

Prior to selection of the permanent study site, a number of locations were surveyed to determine if a suitable animal population, both in numbers and species, existed. An arbitrary figure of 40 percent trapping success for three trap nights was set as a criterion. The various locations were trapped, using 25 National (Tomahawk Trap Company, Tomahawk, Wisconsin) and 25 Sherman trap (Sherman Live Traps, Deland, Florida). The traps were placed in a straight line and spaced approximately 6-12 m apart. One National and one Sherman trap were placed at each trap station (location). Each station was marked with a stake to insure all traps could be located the following morning.

Traps were placed in the areas during the late afternoon and baited with a mixture of 2 parts milo and cracked corn to one part rolled oats. The traps were checked at approximately sunrise the following morning. Total animals trapped, and their identification were recorded then they were released at their site of capture.

Of 10 areas sampled, three had met the criteria as far as animal population was concerned. One location was elim-

inated because no creosote brush was present. A second location though an excellent area, was dropped for preference to the selected site. The study site was chosen for the following reasons: contained suitable animal population (above 40 percent trap success); vegetative types were of the types desired (creosote-mesquite association); ease of access by vehicle; and little grazing by the ranch cattle.

Preparation and trapping of grid

The trap grid was established by placing .91 m, wooden stakes 6 m apart. One National and one Sherman trap were placed at each stake (Figure 1). Two different types of traps were utilized, to determine animal preference, if any; and to compensate for the large or small size of the various animals to be trapped. Stakes and traps were numbered in sequence 1-100. The study grid was 114 m x 24 m, or 2736 sq m (approximately 0.28 hectare).

The study area was trapped one time per week, usually Wednesday, unless adverse weather or some other unforeseen happening occurred. It was felt additional weekly trapping might have reduced flea and/or animal populations and given false indices.

Once the grid was established and weekly trapping began the following procedures were done. Traps were baited as previously described, in the late afternoon. It was necessary to be at the study area at sunrise the following morning to pick up the animals for the hot desert sun caused

Figure 1. Traps at stake site.

mortality very quickly. The animals were picked up at their respective capture sites, and taken to a processing area (Figure 2). Upon completion of processing they were returned to the same stake site and released.

Animal Processing

Each individual was processed separately. A detailed data sheet was maintained on each animal (Figure 3). The processing procedure occurred as follows: The animal was taken from the trap with heavy duty welder's gloves, placed in a large, white enamal bucket (slop jar), a transparent glass lid was quickly fitted on the top. The animal was anesthetized by slightly tilting the lid and spraying ether into the bucket from an aerosol can. Fleas were then removed from the animal by brushing it with a toothbrush over the bucket. The fleas were collected from the bucket with a small camel-hair, artist's brush and placed in a vial containing 70 percent ethanol. Labels, containing date, animal number (which identified its location to a particular data sheet) and contents were placed in each vial. Fleas were later identified in the laboratory using Wheeler's Key to the Siphonaptera of Red Bluff Ranch on Rodents, Rabbits, Hares and Carnivores (1968). The field expedient method used to identify the fleas is described by Stark (1959).

The animal was then weighed and measured and determination of age and sex made. The animals were weighed each time they were trapped but were not remeasured unless they

Figure 2. Animal field processing laboratory.

SHEET NUMBER_____

INDIVIDUAL ANIMAL DATA SHEET - NEW MEXICO PLAGUE PROJECT

1. Species	2. Sex						3. Age					
4. Toe Clip Number												
5. Date Trapped	_____		_____		_____		_____		_____			
6. Trap No. and Type	_____		_____		_____		_____		_____			
Measurements:												
7. Weight	_____		_____		_____		_____		_____			
8. Total Length	_____		_____		_____		_____		_____			
9. Tail Length	_____		_____		_____		_____		_____			
10. Ear Length	_____		_____		_____		_____		_____			
11. Hind Foot	_____		_____		_____		_____		_____			
12. Anal Temperature	_____		_____		_____		_____		_____			
13. Fleas (including sex)												
	M	F	M	F	M	F	M	F	M	F	M	F
(1)	_	_	_	_	_	_	_	_	_	_	_	_
(2)	_	_	_	_	_	_	_	_	_	_	_	_
(3)	_	_	_	_	_	_	_	_	_	_	_	_
(4)	_	_	_	_	_	_	_	_	_	_	_	_
(5)	_	_	_	_	_	_	_	_	_	_	_	_
14. Total Fleas	_	_	_	_	_	_	_	_	_	_	_	_
15. Other Ectoparasites												

16. Observations:

Figure 3. Individual animal data sheet.

were immatures when first trapped. Next, using a telethermometer (Figure 4) the animals anal temperature was taken. Identifications of the animals were made using Burt and Grossenheider's text "A Field Guide to the Mammals." After identification the animals were toe-clipped as described by Blair (1941) then taken back to their capture site and released. All data listed on Figure 3 was completed weekly except the above mentioned items.

After all individual animal sheets were completed for a week's trapping, a weekly data sheet was compiled (Figure 5). Continuous above ground, temperature and humidity readings were taken with a hydrothermograph. Underground burrow readings were made once a week. These readings were accomplished by inserting a hollow, hard-rubber pipe, approximately two inches in diameter down into a burrow area. The burrow was determined active by lowering a piece of apple on a string down the pipe into the burrow. The bait would be eaten if an animal were present. Once an active burrow was found, readings were made with a hydrothermometer (Model 15-3030, Will Scientific Co.). This instrument was equipped with 7.3 m leads, which attach to sensor devices. The sensors were lowered into the burrow and the temperature and humidity were measured by the instrument above ground. Wind and rainfall were measured with instruments from a U.S. Air Force weather kit.

The following procedures were done to supplement the receiving data from the study site:

Figure 4. Telethermometer for taking animal temperatures

ECOLOGICAL SURVEY SHEET - NEW MEXICO PLAGUE PROJECT

1. Location_____ 2. Date_____

3. Number of Traps (a) N_____ 4. Number Animals Trapped____
(b)S_____

5. Percent Trapped_____ 6. Pick up time_____

Weather Conditions: 7. Wind (MPH)_____ 8. Sky_____

9. Moon_____ 10. Rainfall_____ 11. Soil Cond._____

Temperature: Constant Recording, Above Ground

12. Min._____ 13. Max._____ 14. Aver._____

Single Reading, Below Ground 15. _____

Humidity: Constant Recording, Above Ground

16. Min._____ 17. Max._____ 18. Aver. _____

Single Reading, Below Ground 19._____

Animal-Ectoparasite Data:

20. Species Collected (Taken from Individual Animal Sheets):

		Ectoparasite Data	
Animal Species	Fleas	Flea Index	Other Ectoparasites
1._____	_____	_____	_____
2._____	_____	_____	_____
3._____	_____	_____	_____
4._____	_____	_____	_____
5._____	_____	_____	_____

6. Total Animals_____ 7. Total Fleas_____

8. Total Flea Index_____ 9. Total Other_____

10. Animals Collected for First Time_____

11. Collected Previously_____

12. Observations:

_____

Figure 5. Weekly summary data sheet.

1. An estimate of the population of the study area was made by using the Schnabel population estimate (Schnabel 1938).

2. Routine trapping was done in adjacent areas of the ranch to collect animals to make study skins of the representative animals in the study site without disturbing the population on the site. Study skins were prepared as described by Anthony (1950).

3. To determine if the plague was present in the animal population in or around the study site routine blood and/or tissue (spleen) samples were taken and sent to the New Mexico, Environmental Improvement Agency, for laboratory work-up. Animals from the site were not utilized unless they had died during processing (too much ether, etc.).

Laboratory Studies

This portion of the study was conducted at the U.S. Department of Agriculture's (U.S.D.A.), Insects Affecting Man and Animals Laboratory, Gainesville, Florida.

Fleas used in the tests were reared by the above laboratory as described by Cole et al. (1972), four-to-seven-day-old fleas were utilized for the tests. All were Xenopsylla cheopis, the oriental rat flea.

The rats used for the tests were from two sources. Hooded rats (cross between the wild Norway rat and the domestic white, laboratory rat) obtained from the U.S.D.A's

Laboratory animal colony, and wild, roof rats Rattus rattus Fischer, which were live trapped from the University of Florida's Poultry Research Unit located adjacent to the U.S.D.A. Laboratory. The traps utilized were National (Tomahawk) foldable, wire traps (3.3 x 5.0 x 8.3 cm). The traps were baited with apple in the afternoon and the rats picked up the following morning. No data on trap success, numbers collected, etc. as with the field study, were maintained. These rats were trapped for test purposes only. The rats were checked for fleas as described in the field study but this was only to insure no other species or wild strains of Xenopsylla cheopis were introduced into the colony cages.

Once the rats were checked for fleas (none were found) they were placed in a large colony holding cage, 3.6 x 5.5 x 7.3 m (Figure 6). The cage was made rat-proof by completely lining the inside, excluding the plywood ceiling, with .6 cm hardware cloth. This prevented the rats from chewing through the wood and escaping. The cage was sunk into the ground approximately 30.5 cm deep, white sand was placed inside the cage to provide a burrowing medium for the rats. In addition cardboard boxes of various sizes were placed inside to provide harborage. Standard laboratory rat chow (Purina-Ralston Company) and water were provided continuously.

Methods and Procedures--The literature produced no guide for the methods used in this research. Many studies on the effectiveness of various animal systemic insecticides have

ure 6. Rat colony holding cage.

Clark and Cole (1968) evaluated a number of insecticides for systemic action in rats for flea control. Of these, fenthion (0,0-dimethyl O-[4-(methylthio)-m-tolyl] phosphorothicate) was one of the more successful materials. Further evidence of this insecticide's potential as a systemic was demonstrated by Clark et al. (1971). In this case it was shown effective against some of the fleas on field rodents and cottontail rabbits in New Mexico. From these data it was decided to use fenthion as the insecticide of choice for these tests.

Initial tests were conducted to determine if sticky materials such as vacuum grease or vaseline (petroleum jelly) could be used as a carrier for an insecticide such as fenthion. The first tests were conducted with vacuum grease but it was not as acceptable to the rats and later dropped and vaseline used exclusively. Solutions containing 1, 3, and 5 percent fenthion in hexane were thoroughly mixed with the carrier. During these first tests the material was smeared on the front feet of R. rattus.

The process took place as follows. A single rat was caught from the large, holding cage using a long handled [illegible]. While still in the net the rat was anesthetized with chloroform and combed to insure no fleas were [illegible]. Then the material was [illegible]

[illegible] rat was provided [illegible] and water and [illegible]. At this time 100 fleas from the U.S.D.A.'s colony were placed in the container. Two repetitions of each concentration and 2 checks were run concurrently, the rats were checked daily for fleas and 100 fleas were added per day for one week.

Once results indicated the material would kill the fleas present further tests were initiated. Artificial rat runs (Figure ?) with removable centers were made to simulate a rat's movement under field conditions. At first the sticky material was placed on the removable center and it returned to its original position. This was found unsuccessful. Next the material was placed on both sides of the center and a bait (non-treated) was placed in the center hole. This was to attract the rat into the center and thereby cause it to walk across the treated material. This method was only partially successful. The only way to insure the rat would pick up enough material to effectively reduce the [illegible] was to force it to run [illegible] across the material at least 3 times. Many series of tests were [illegible] with hooded rats for X. [illegible] runs were made for this type experiment. After numerous trials it was apparent no practical control method was feasible here.

The last group of tests performed involved X. [illegible]

Figure 7. Individual Animal holding container.

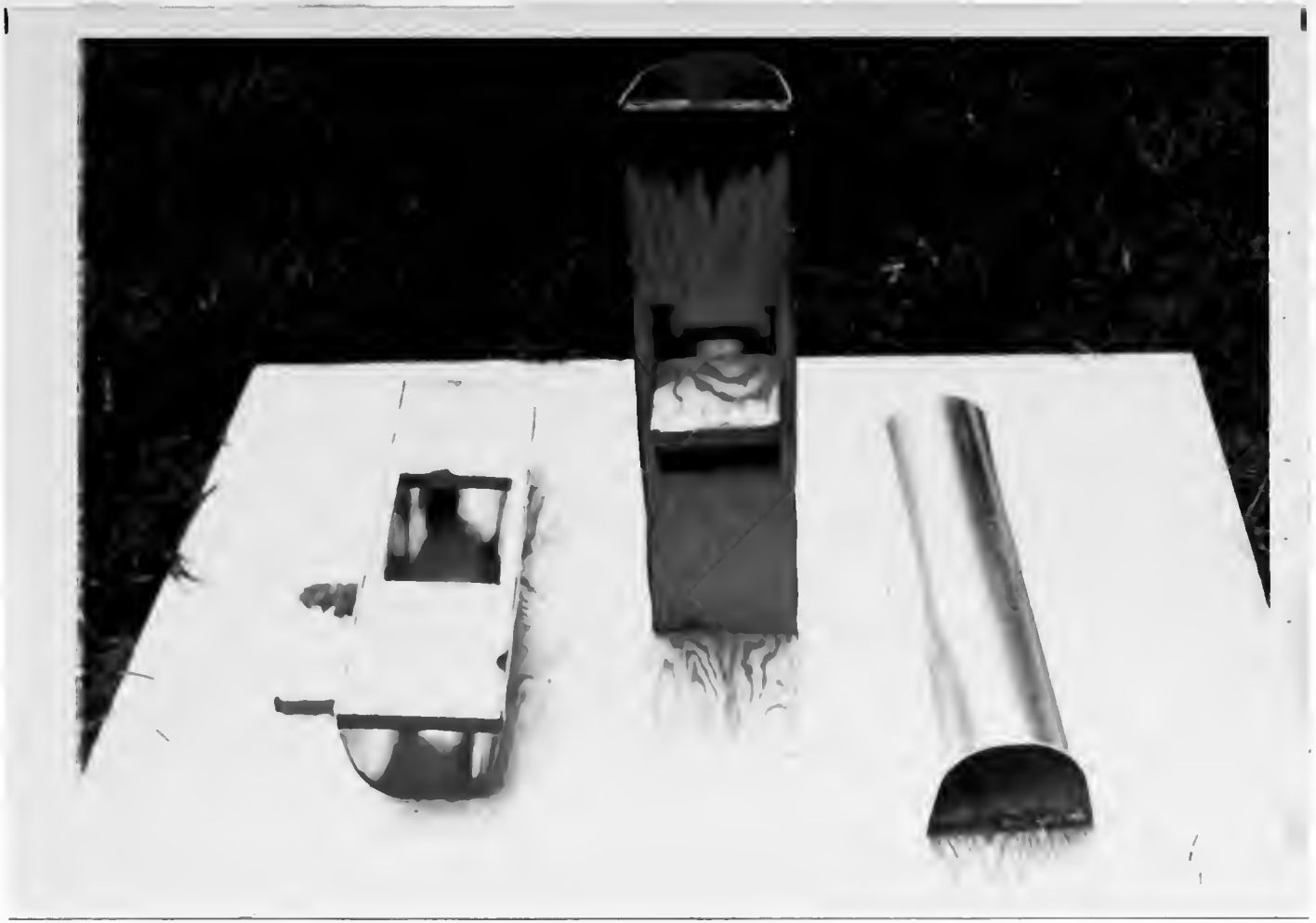

Figure 8. Artificial rat runs.

Five rats were placed in a large cage [illegible]. [illegible] were placed on each rat prior to placing them in the cage. A 5 percent fenthion in vaseline carrier was placed in the runs as previously described. The rats were provided with water but their only food source (apple) was within the artificial rat run. This was a last attempt to see if this technique might have any practical value. The rats fed on the apple but no significant reduction was noted in the fleas on the rats. It therefore, became apparent that this method in its present form was not a successful method of flea control by the systemic route. Further discussion on the future feasibility of this technique and closely related methods are included in the next section.

RESULTS AND DISCUSSION

Field Studies

Discussion of Aspects Relating to the Study Site

No plague infected animals were found on the research plot or any part of Red Bluff Ranch during the months of study. As previously stated, Kartman (1960) reported plague from 2 human cases and a rabbit epizootic approximately 8 km north of the study area.

An initial objective of the project was to find a plague-free area, have a natural epizootic occur, then follow the outbreak through the animal population, studying the ecological relationships of the disease to the infected and uninfected animals and their fleas.

A study of this nature was done by Lechleitner et al. (1962) in Colorado, using a colony of prairie dogs, Cynomys gunnisoni gunnisoni (Baird), as study animals. They had initiated a basic study of the prairie dog colony without any knowledge of the oncoming plague epizootic.

The epizootic when it did occur, swept through the colony and killed every prairie dog in the area of observation so quickly it limited the amount of data they could collect on the movement of the epizootic.

After the epizootic began the workers started collection and observation of other animal species in the area. Animals present that had been previously found infected with plague (Kartman 1970) included, the deer mouse, Peromyscus maniculatus (Wagner); golden-mantled ground squirrel, Spermophilus (Citellus) lateralis (Say); mountain pocket gopher, Thynomys talpoides (Richardson); and Richardson's ground squirrel, Spermophilus (Citellus) richardsonii (Sabine). Apparently none of the animals except Richardson's ground squirrel were affected by the disease. This species was affected only in the immediate area of the prairie dog colony and those, even in this area, were not affected if they had entered their summer dormancy period.

No opportunity arose for such a study at Red Bluff Ranch but future studies in plague ecology will have to include this work if the host-flea relationships, prior to, during and after a plague epizootic are to be known.

Trapping Results

Trapping on the study plot began March 13, 1968 and continued through July 16, 1968. A total of 17 trap nights resulted in the capture of 306 animals, and represented 903 captures and recaptures. A summary of trapping results is given in Table 1. After the first week of trapping, percent trapping success was fairly constant. A general increase in recapture rates occurred throughout most of the trapping period. The last 2 trap nights were lower but this was due

Table 1. Trapping results, including captures and recaptures, from a 24 x 114 meter study plot on Red Bluff Ranch, New Mexico, March 13 through through July 16, 1968.

Date	Animals captured	Percent Success[a]	Recaptures	Recapture percentage
Mar. 13	26	13	0	0
Mar. 28	41	21	15	34
Apr. 4	41	21	21	31
Apr. 10	45	23	23	51
Apr. 17	47	24	24	51
Apr. 24	54	27	32	57
May 1	58	29	31	53
May 6	54	27	36	67
May 13	56	28	43	77

[a]Based on 200 traps per night.

Table 1. (Continued)

Date	Animals captured	Percent Success[a]	Recaptures	Recapture percentage
May 21	68	34	45	66
May 28	65	33	48	74
June 4	78	39	48	62
June 11	64	32	49	77
June 18	65	33	52	80
June 26	57	29	49	86
July 9	48	24	31	65
July 16	46	23	30	65

[a]Based on 200 traps per night.

to excessive rains that occurred the first week in July (12.7 cm in one week, nearly one-half the average total for an entire year).

High recapture rates were recorded throughout the tests. Stark and Miles (1962) had similar trapping success with the California meadow mouse, Microtus californicus (Peale) during a plague study in the San Francisco Bay area of California. These high recapture rates are unusual. Data presented by Mosby (1963), including numerous animal species, showed very low recapture rates, usually less than 10 percent.

This high recapture rate, according to Mosby (1963), gives accurate population estimates when the Schnabel (1938) method of population estimates is used.

Population Estimate--The population estimate for this study was made from the animals captured and/or recaptured from the first through the fifth trap nights. It was thought use of further trap night data would cause an overestimate of the population. This was due to immigration into the study plot of animals from adjacent locations. Results of the estimate are given in Table 2. When averaged, the data indicated an estimated population of 100 animals on the 24 x 114 m study plot.

Trap preference

To insure the maximum efficiency in trapping animals one should use the trap or traps best suited for the study. Rael et al. (1969) had demonstrated that National (Tomahawk) and Sherman traps were efficient in trapping small animal

Table 2. Estimate of the animal population on the 24 x 114 meter study plot on Red Bluff Ranch, New Mexico.[a]

Date	(A) Animals Trapped	(A-C) Animals marked	(B) Marked Animals in area	(A)(B) Product	Sum of (A)(B)	(C) Recaptures	Sum of (C)	$\frac{\Sigma(A)(B)}{\Sigma C}$ Estimated Population[b]
March 13	26	26	0	0	0	0	0	0
March 28	41	26	26	1066	1066	15	15	71
April 4	41	20	52	2132	3198	21	36	89
April 10	45	22	72	3240	6438	23	59	109
April 17	47	23	94	4418	10856	24	83	131

[a]Data represent only the first five trap nights of study.

[b]Schnabel (1938) method of estimating animal populations.

grazing on Red Bluff Ranch. In this study [illegible] one Sherman trap were placed at each station. It was unknown what the trapping efficiency of each type trap would be prior to the study. However, it was known that a tiny Perognathus spp. would slip through the wire sides of the National trap, and that the small Sherman trap would not trap a rabbit-size animal. This made it necessary to use both traps at all stations on the study plot.

A comparison of the trapping success of the two traps was made and is found in Table 2. It was apparent that animal size (as described above) was one of the dominating factors in determining trap success. Perognathes flavus Baird, was caught entirely in the smaller Sherman traps, while the larger animals, such as Spermophilus (Citellus) spilosoma Bennett, and Sylvilagus audubonii (Baird) were all trapped in National traps. Peromyscus leucopus (Rafinesque), and Onychomys leucogaster (Wied), both small animals, were trapped well in both traps. Dipodomys merriami Mearns and D. ordii Woodhouse, are approximately the same size animals but the latter showed a definite preference to the National trap (21 percent difference). D. spectabilis Merriam and Neotoma micropus Baird were nearly all (96 and 98 percent respectively) trapped in National traps. Mosby (1963) states open-mesh traps improve efficiency for trapping most animals because unit scent is carried out on currents of air. In addition, most animals will enter traps more readily if they can look in one end

Table 3. Comparison of trapping success by animal species, between National (Tomahawk) and Sherman live traps on Red Bluff Ranch, New Mexico.[a]

Animal species	March		April		May		June		July		Total		Percent Total[b]	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Dipodomys merriami	19	6	29	2	61	35	53	36	16	12	178	91	66	34
D. ordii	16	0	24	4	72	11	42	8	21	2	175	25	87	13
D. spectabilis	5	0	8	1	29	2	21	0	11	0	74	3	96	4
Neotoma micropus	7	0	5	0	21	0	35	2	13	0	81	2	98	2
Onychomys leucogaster	1	0	0	1	2	5	1	0	0	0	4	6	40	60
Peromyscus leucopus	3	2	0	6	9	11	4	3	0	0	16	22	42	58
Perognathus flavus	0	1	0	2	0	14	0	35	0	6	0	58	0	100
Spermophilus (Citellus) spilosoma	1	0	0	0	25	0	19	0	2	0	47	0	100	0
Sylvilagus audubonii	2	0	3	0	6	0	5	0	7	0	23	0	100	0

[a]Represents 15 traps nights from March 13 to July 16, 1968.

[b]To nearest percent.

and see out the other. This is the case with [illegible] but Sherman traps have solid sides and end. These latter two reasons and size seemed to be the only factors determining trap efficiency during this study.

Animal Species Trapped

Nine species of animals were collected on the study site. Of these, eight were rodents and one was a Lagomorph (Rabbit). The taxonomic classification of these animals is listed below. Classification follows that of Hall and Kelson (1959).

Order: Lagomorpha
Family: Leporidae
Sylvilagus audubonii (Baird)
Order: Rodentia
Family: Sciuridae
Spermophilus (*Citellus*) *spilosoma* Bennett
Family: Heteromyidae
Perognathus flavus Baird
Dipodomys ordii Woodhouse
Dipodomys merriami Mearns
Dipodomys spectabilis Merriam
Family: Cricetidae
Peromyscus leucopus (Rafinesque)
Onychomys leucogaster (Wied)
Neotoma micropus Baird

The relative abundance of the different species is given in Table 4, included also, are common names.

Table 4. Relative abundance of animals caught during 17 trap nights from March 13 through July 16, 1968 on Red Bluff Ranch, New Mexico.

Animal species	Total caught	Percent of all species
Dipodomys merriami	92	30.0
D. ordii	61	19.9
Perognathus flavus	36	11.8
Peromyscus leucopus	28	9.1
Neotoma micropus	23	7.6
Dipodomys spectabilis	21	6.9
Spermophilus (Citellus) spilosoma	20	6.5
Sylvilagus audubonii	19	6.2
Onychomys leucogaster	6	2.0

[illegible] more: Dipodomys merriami, Merriam's Kangaroo rat; [illegible] D. ordii, Ord's Kangaroo rat; Perognathus flavus, silky pocket mouse; Peromyscus leucopus, white-footed mouse; [illegible] Neotoma micropus, Southern plains woodrat; Dipodomys [illegible] spectabilis, Banner-tail kangaroo rat; Spermophilus (Citellus) [illegible] spotted ground squirrel; Sylvilagus audubonii, desert cottontail rabbit; Onychomys leucogaster, Northern grasshopper mouse.

Host-plague Relationships

The plague bacillus has been found in numerous animal species in New Mexico (Wael et al. 1969) (Kartman 1970). Of the 9 animal species collected during this study, 7 have been found infected with plague. The literature revealed no Dipodomys spectabilis and D. merriami with plague infections.

Various workers have tried to name certain animal species as reservoirs of plague in the western United States. Ground squirrels were incriminated as reservoirs by Meyer (1942). Later workers, Kartman et al. (1959) and Lechleitner et al. (1962), list the prairie dog as a primary reservoir. In 1968, in Denver, Colorado, the fox squirrel, Sciurus niger, Linnaeus, was the principal animal infected by plague in this epizootic. No other animals were found positive (Hudson et al. 1971). Rattus norvegicus (Erxleben), considered one of the principal plague-associated animals in the world (Pollitzer 1954) was collected in the same areas as the fox squirrel but was not found infected. Stark (1959) states Microtus spp. and Peromyscus spp. were highly plague resistant in laboratory tests in California. In other areas these have been susceptible animals. To date no author has adequately defined the host-plague relationships in the United States.

Animal Temperatures

Prior to initiation of this study it was thought that

[illegible] animal temperatures [illegible] factor to determine [illegible] plague epizootics [illegible] factor in determining the hosts that are actually refractory to the disease, i.e., the true reservoirs. No known data was available on animal temperatures as related to plague. Miller and Stebbins (1964) found, when Dipodomys merriami body temperature approached 105°F (40.6°C) the animal would expire. A number of these and other species collected during the study died, apparently for the above reason.

Animal temperatures (anal) were taken on all animals collected. There was such a wide range of temperatures within species and overlapping of temperature among all species that no attempt was made to correlate any of the data to plague epizootics or potential reservoir studies, but because so little data has been published on temperatures of small rodents or rabbits it has been included here. The average temperature of each species by month, plus the maximum and minimum temperature recorded for each animal is given in Appendix I-Table 1).

[illegible] Relationships

Little is known about the life histories of the rodents collected during the study in relation to plague. Pollitzer (1954) suggests there might be a relation of the sex of the [illegible] to the occurrence of plague. His only explanation was that female animals spend more time in the burrow rearing the young. Males, at least in many rodent species pro-

[illegible] of the food [illegible] the young. This places the male in a position to be more in contact with other animals [illegible] by direct contact or by exchange of fleas. A breakdown of adults, animal, by sex is given in Table 5. The ratio of males to females is fairly equal in most cases. The exceptions were species that only had 14 or less total animals trapped.

Host-Flea Relationships

Fleas differ greatly in their host preferences and ability to transmit plague to man or other animals. To adequately study these relationships one must know the species of fleas and their hosts in the study area.

During the study at Red Bluff Ranch 1,436 fleas, representing 13 species were collected. The classification of the fleas following the synonymy of Hopkins and Rothschild (1953) (1956), is listed below.

Order: Siphonaptera

Family: Hystrichopsyllidae

Subfamily: Neopsyllidae

Meringis hilsingi Eads and Menzies

Meringis dinodonys Kohls

Meringis [illegible]

Meringis mexica Herlan

Subfamily: Anomiopsyllinae

Anomiopsyllus neomexicanus

Table 5. Percent adult males and females of each species trapped from the 24 x 114 meter study plot on Red Bluff Ranch, New Mexico

Animal Species	Number trapped Male	Number trapped Female	Total Number[a]	Percent Male	Percent Female
Dipodomys merriami	50	40	90	56	44
D. ordii	33	27	60	55	45
D. spectabilis	10	10	20	50	50
Neotoma micropus	15	8	23	65	35
Onychomys leucogaster	2	4	6	33	67
Peromyscus leucopus	12	11	23	52	48
Perognathus flavus	18	14	32	56	44
Spermophilus (Citellus) spilosoma	9	5	14	64	36
Sylvilagus audubonii	8	5	13	61	39

[a]Sex of immature specimens could not be determined, numbers in Table represent only adult animals.

Family: Ceratophyllidae

[illegible]

[illegible]

Orchopeas sexdentatus (Baker)

Thrassis acidis compestris Prince

Thrassis fotus (Jordan)

Family: Rhopalopsyllidae

Polygenus gwyni (Fox)

Family: Pulicidae

Subfamily: Pulicinae

Echidnophaga gallinacea (Westwood)

Subfamily: Spilopsyllinae

Hoplopsyllus glacialis affinis (Baker)

Numerous fleas have been found infected with the plague bacillus, according to (Pollitzer 1954) and (Stark et al. 1966) this does not necessarily make the species a potential vector of plague. Certain flea species are themselves susceptible to plague, others are resistant enough to the organism that they may be considered reservoirs themselves (Rael et al. 1969). Many workers consider the fleas vector efficiency as a guide for determining its potential for plague transmission. Pollitzer (1954) describes the method for determining the vector efficiency. No reference could be found that states at what vector efficiency fleas are considered potential plague vectors. Xenopsylla cheopis, one of the most important vector's of plague in the world,

during [illegible] species of [illegible].

[illegible] are considered potential plague vectors. Thrassis fotus has a vector efficiency of 0.1. No vector efficiency data could be found on M. anidia carnestris. Leonosyllus wagneri has a vector efficiency of 0.01, and Orchopeas sexdentatus 0.17. Echidnophaga gallinacea, the stick-tight flea, has a vector efficiency of 0.25. No data on vector efficiency could be found on the other flea species collected during the study. The data on vector efficiency were taken from Stark et al, (1966).

Flea Indices

One of the most used and misused tools in the study of flea-plague relationships is the flea index. Each worker seems to have his own method of data presentation, usually determined by his interests and/or method of collection.

This research is no exception, but rather than use only one approach as done by most workers, the data on flea indices will be given graphically by total fleas and total animals per month (Figure 9); total fleas per animal host per month (Figures 10-17); and in Table form, first as a monthly summary of flea indices by animal species (Table [illegible]), secondly by individual flea species per month on each host species (Appendix II, Tables 1-9). Indices on Dipodomys merriami, D. ordii, Perognathus flavus, and

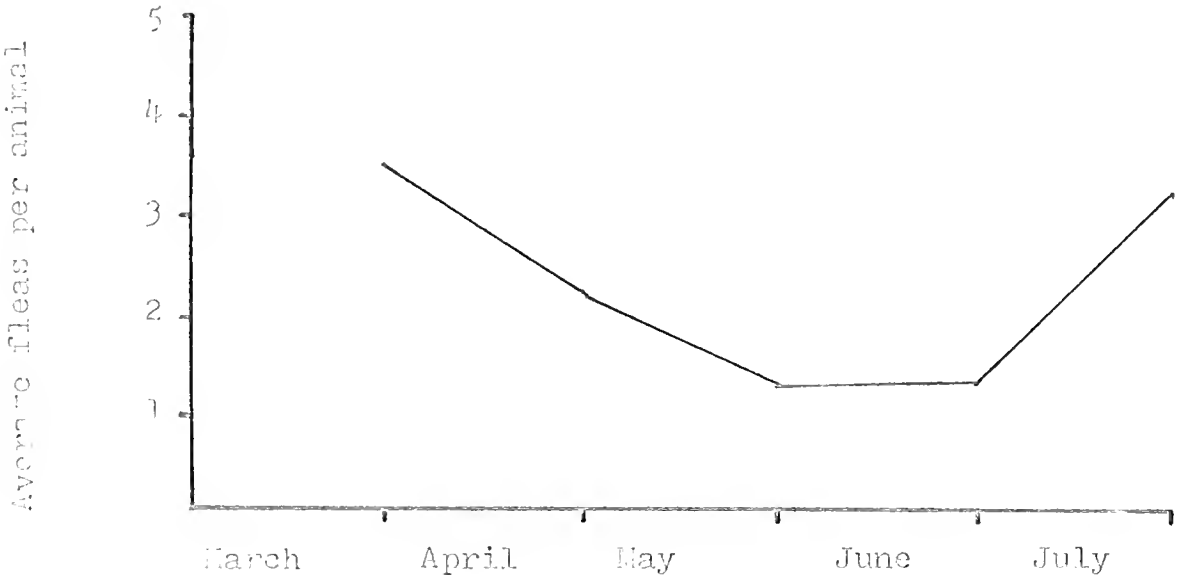

Figure 9. Total flea indices for animals collected March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.

Table 6. Summary of weekly flea indices for all hosts made during the study period, March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.[a]

b	March 13	March 20	April 4	April 10	April 17	April 24	May 1	May 6	May 13	May 21	May 28	June 4	June 11	June 18	June 26	July 9	July 16
1	1.3 (10)	1.5 (15)	2.1 (15)	0.6 (17)	0.2 (14)	0.1 (20)	0.1 (23)	0.2 (18)	0.2 (19)	0.1 (18)	0.1 (19)	0.4 (26)	0.4 (23)	0.1 (21)	0.3 (19)	0.1 (14)	0.0 (16)
2	1.6 (6)	0.8 (11)	1.2 (13)	0.1 (15)	0.3 (12)	0.0 (13)	0.0 (14)	0.1 (15)	0.0 (15)	0.1 (19)	0.0 (20)	0.0 (13)	0.0 (10)	0.0 (13)	0.1 (13)	0.0 (10)	0.0 (13)
3	18 (2)	9.9 (3)	12 (4)	11 (5)	5.0 (3)	5.0 (4)	5.7 (6)	1.7 (3)	3.3 (6)	2.2 (9)	1.4 (7)	1.7 (6)	1.0 (5)	0.2 (5)	0.0 (5)	0.4 (3)	0.0 (5)
4	9.3 (3)	12.7 (4)	10 (3)	2.5 (2)	13.8 (4)	8.5 (2)	1.5 (2)	15 (3)	9.2 (6)	11 (5)	3.2 (5)	12 (8)	9.8 (10)	2.8 (8)	4.2 (10)	31 (5)	7.5 (7)
5	c	4.0 (1)	0.0 (1)	c	0.5 (2)	c	0.0 (1)	0.0 (1)	c	c	c	c	c	3.0 (1)	c	0.0 (1)	c
6	c	0.0 (1)	1.0 (1)	0.0 (1)	0.3 (4)	0.0 (3)	1.0 (1)	0.0 (3)	0.0 (3)	0.0 (2)	0.0 (5)	0.0 (12)	0.0 (11)	0.0 (6)	0.0 (6)	0.0 (2)	0.0 (3)
7	3.0 (1)	3.5 (4)	4.5 (2)	0.5 (4)	0.8 (4)	1.0 (6)	1.5 (4)	0.0 (1)	1.4 (5)	1.9 (7)	0.1 (3)	3.0 (3)	4.0 (2)	2.0 (2)	c	0.0 (1)	c
8	c	3.0 (1)	c	c	1.0 (2)	0.5 (2)	0.5 (6)	2.8 (5)	2.0 (3)	1.2 (6)	0.5 (6)	0.1 (9)	0.0 (2)	0.0 (5)	0.3 (3)	4.0 (3)	2.0 (1)

Table 6. (Continued)

	March		April				May					June				July	
	13	20	4	10	17	24	1	6	13	21	28	4	11	18	26	9	16
9	1.0 (1)	6.0 (1)	10.5 (2)	37.0 (1)	6.0 (2)	3.0 (2)	9.0 (1)	5.0 (3)	0.0 (1)	6.0 (1)	2.3 (0)	10.0 (1)	3.0 (1)	17.5 (2)	0.0 (1)	13.0 (3)	3.7 (3)

[a]Number in parentheses represents number of animals taken that week.

[b](animal): 1. Dipodomys merriami 2. D. ordii 3. D. spectabilis 4. Neotoma [illegible]
5. Onychomys leucogaster 6. Perognathus flavus 7. Peromyscus leuc[illegible]
8. Spermophilus (Citellus) spilosoma 9. Sylvilagus audubonii.

[c]No animals of this species collected.

[illegible] were [illegible] included in the [illegible].

Only trends in flea [illegible] data presented graphically. The results indicate a general decrease in indices from March to July. This would be more apparent if false peaks, produced by a few animals with many fleas, e.g. Table 6, April 10, Sylvilagus audubonii, index 37.0 were not included. If interpreted by results in Figure 16, it would appear that Sylvilagus audubonii had a sharp increase in fleas in April. When a summary of weekly data is compiled (Table 6) and the numbers of animals of each species collected is listed, it becomes apparent that a very few animals can have a tremendous influence on total flea indices. Data presented graphically, especially over extended periods of time does show definite trends in flea populations. These variations are probably related to monthly and yearly climatic conditions (Pollitzer 1954). The New Mexico Environmental Improvement Agency has provided unpublished data on flea indices from their continued study on Red Bluff Ranch. This material is given in Appendix II, Figures 2, 4 and 8. The data is included for comparison to the indices on the same animal species of this study. The 3 animals compared are Dipodomys spectabilis, [illegible] and Sylvilagus audubonii. The former has similar indices while the latter 2 vary somewhat. [illegible] considered due to unusually [illegible]

spilosoma throughout the study period. The total flea index represented by Figure 9 shows indices of 1.5 to 3.5 per animal. This demonstrates the need for individual indices for fleas and their hosts. In a plague endemic area it is essential to know the indices of the individual fleas and animals if plague epizootics are to be predicted. Graphical data is useful in planning yearly control operations but does not have the definitive data needed for plague studies.

To adequately follow a flea population and their hosts one needs to know the flea index of each flea species during a study. This information is given in Appendix II. Tables 1 through 9. This data provides a fast, efficient method of determining flea indices that are useful in plague studies.

When plague epizootics occur in wild animal populations they are usually perpetuated by one, or only a few, of the total animal species in an area, and one or more fleas associated with the animal hosts (Stark and Miles 1963) (Lechleitner et al. 1962) (Hudson et al. 1971).

The data in the Tables reveals only one potential plague problem. In Appendix II, Table 8, Spermophilus (Citellus) spilosoma had flea indices of 3.0 ([illegible])

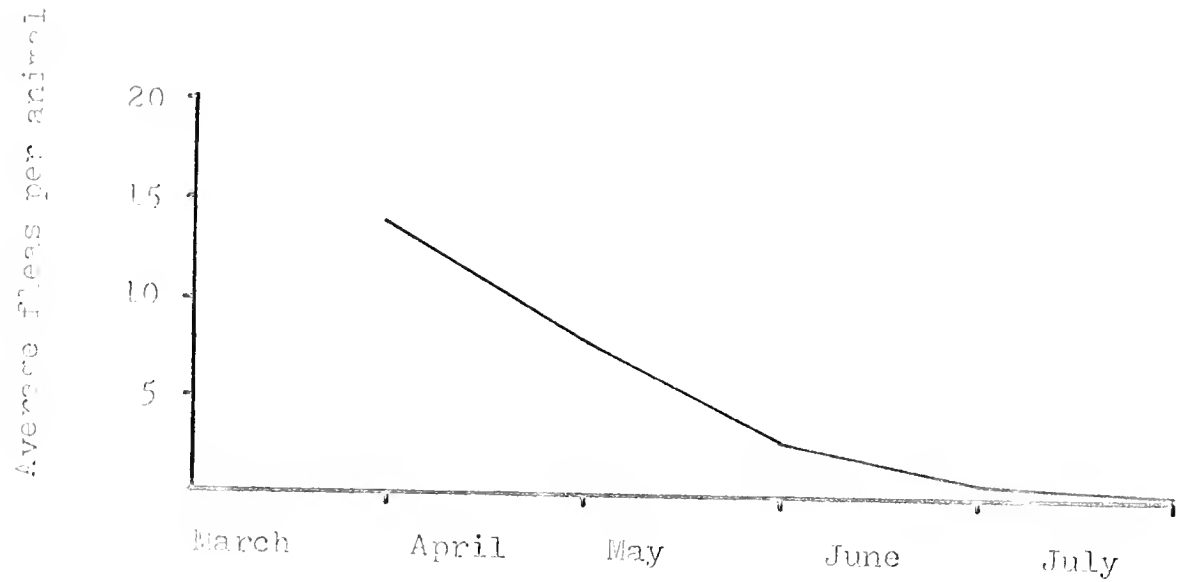

Figure 10. Flea index for Dipodomys spectabilis, March 13 through July 16, 1968, from the study site on Red Bluff Ranch, New Mexico.

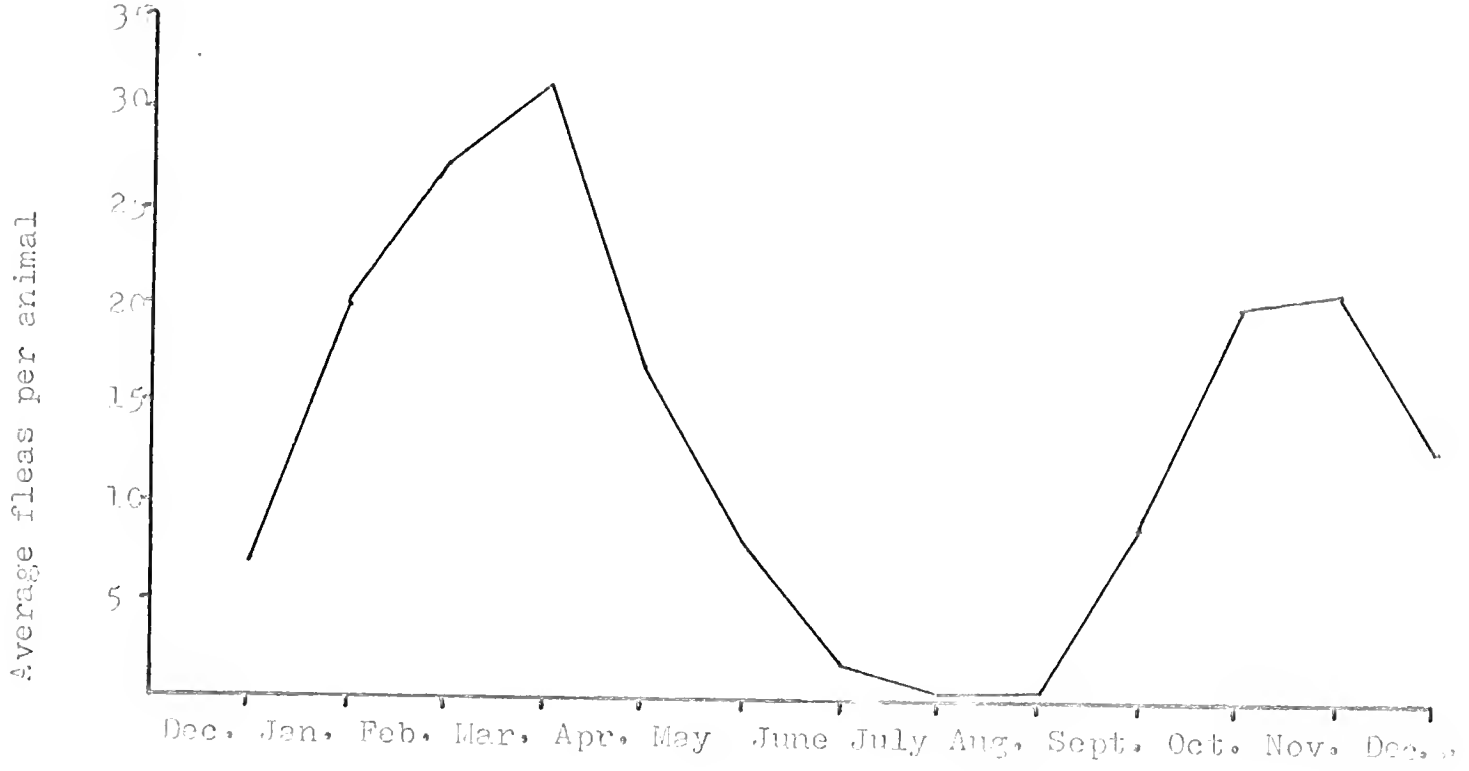

Figure 11. Flea index for Dipodomys spectabilis, December 1969 through December 1970 at Red Bluff Ranch, New Mexico.

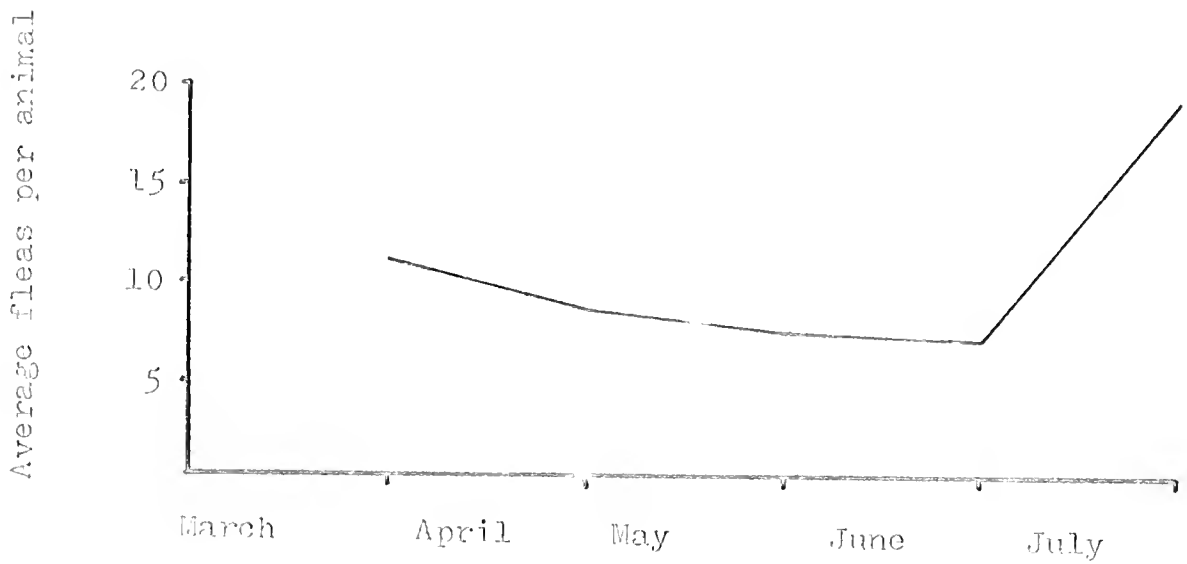

Figure 12. Flea index for Neotoma micropus, March 13 through July 16, 1968, from the study site on Red Bluff Ranch, New Mexico.

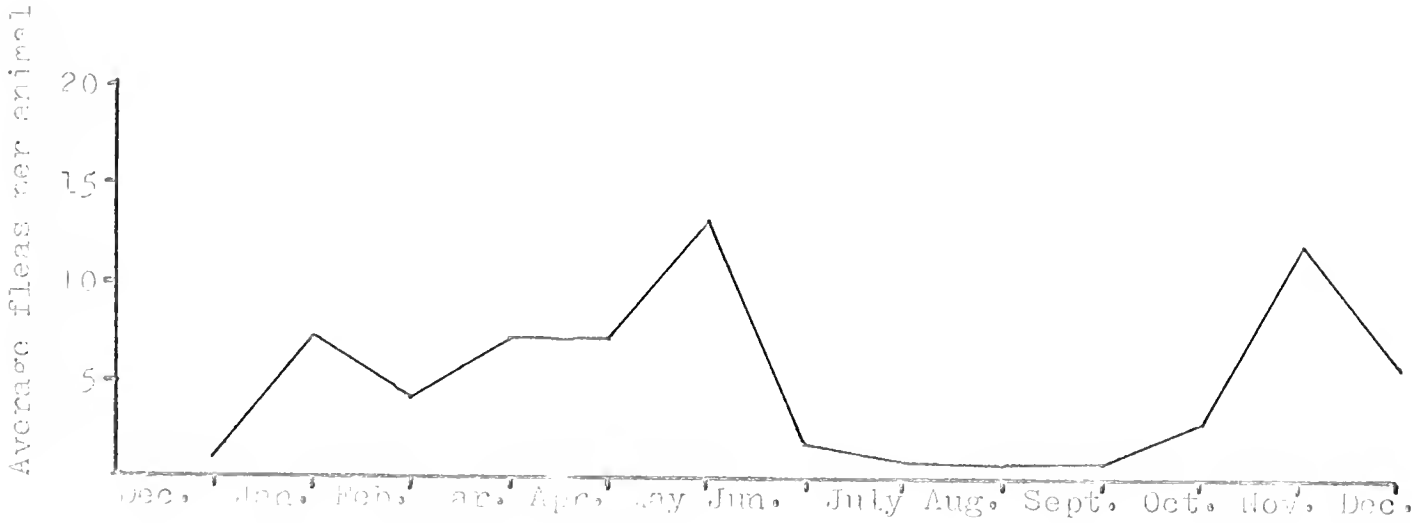

Figure 1. Flea index for Dipodomys nitratoides, December 1969 through December 1970, [illegible] New Mexico.

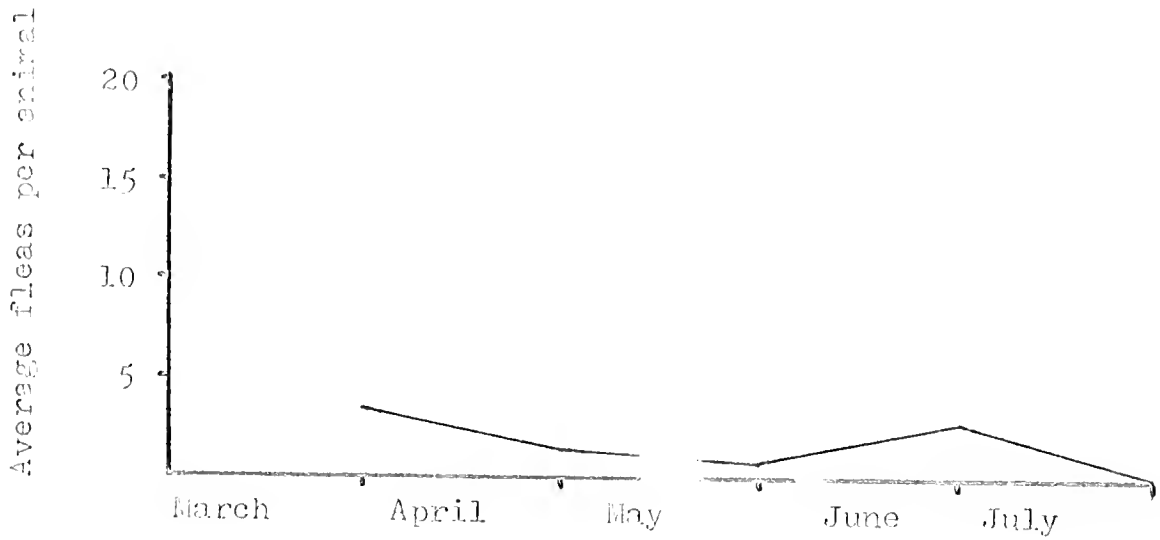

Figure 14. Flea index for Peromyscus leucopus, March 13 through July 16, 1968 for the study site on Red Bluff Ranch, New Mexico.

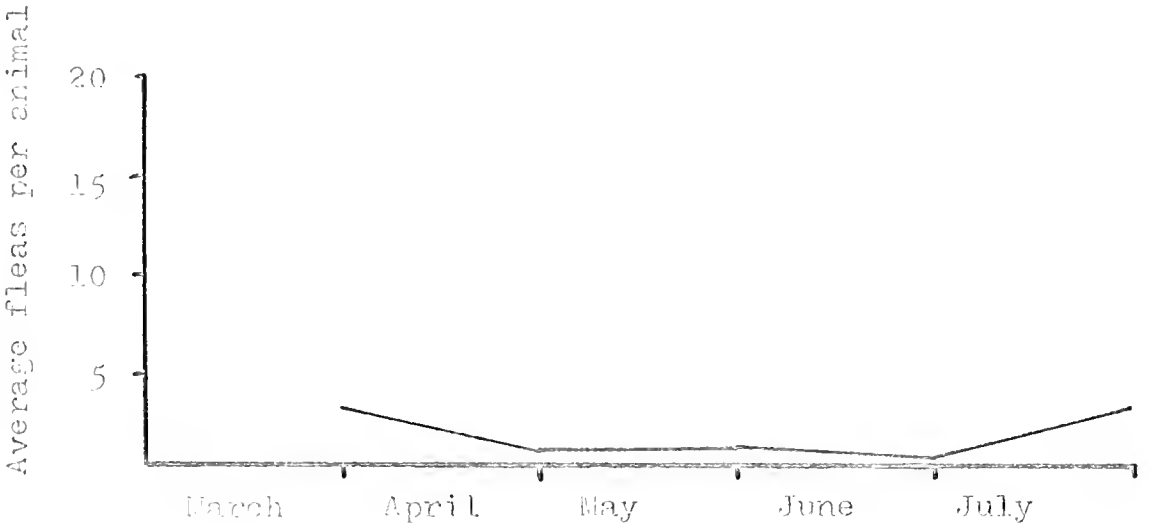

Figure 15. Flea index for Spermophilus (Citellus) spilosoma, March 13 through July 16, 1968 from the study site on Red Bluff Ranch, New Mexico.

Figure 16. Flea index for Sylvilagus audubonii, March 13, through July 16, 196[illegible] from Red Bluff Ranch, New Mexico study site.

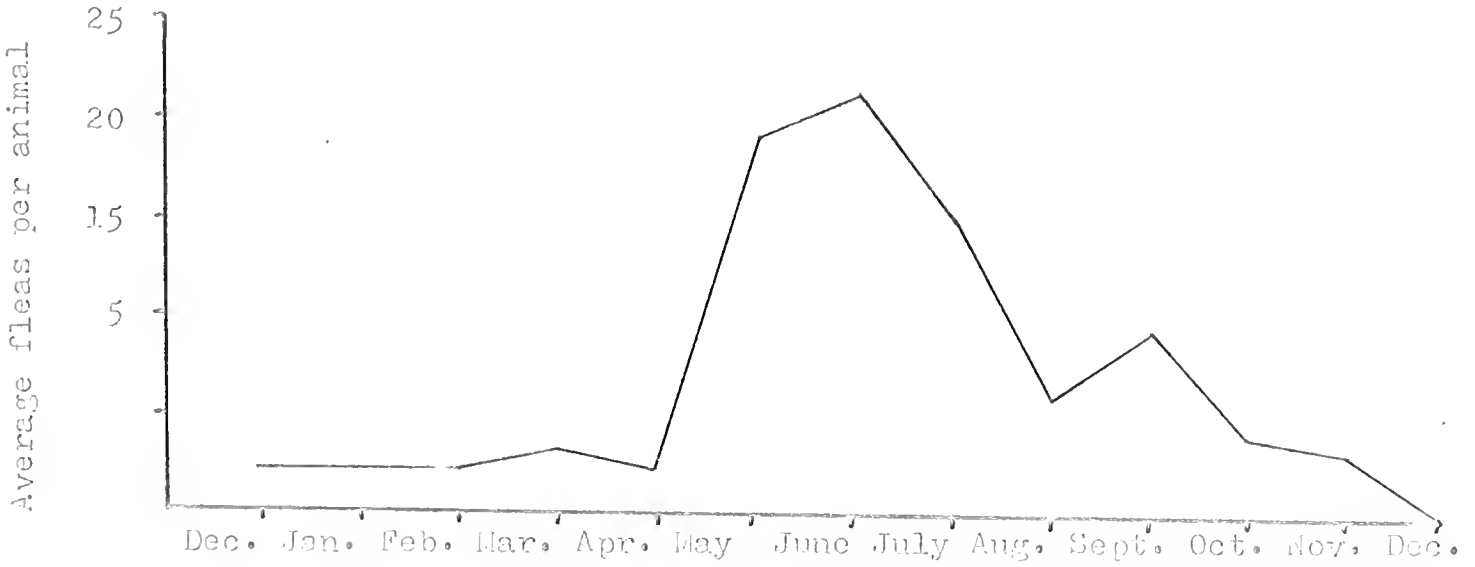

Figure 17. Flea index for Sylvilagus audubonii, December 1969 through December 1970 at Red Bluff Ranch, New Mexico.

[illegible] for [illegible] with plague epizootics (Eskey and Haas, 1940). This does not mean a plague epizootic is imminent but by having the data available future indicators such as animal die-offs, can be quickly detected and measures taken to alert the area to a possible epizootic.

In addition to the data discussed above, Appendix II, Tables 1 through 9, give host-flea preference information including relative abundance of various flea species on different hosts.

Laboratory Studies

The laboratory study of flea control techniques was conducted at the U.S.D.A., Insects Affecting Man and Animals Investigations Laboratory, Gainesville, Florida. This portion of the research was an attempt to evaluate some new, potential, plague control measures.

Various methods have been used in flea control programs involving plague epizootics in the western U.S. As previously mentioned in the review section the problem of controlling wild animal fleas is primarily one of application method rather than effective insecticide. The tests in this research attempted to test a new concept for flea control. Past control measures have involved spraying and dusting various insecticides (Ryckman et al. 1953) (Miles and Villeme 1953) (Pollitzer 1954), and bait box [illegible]

insecticide dusts (damaged by [illegible]). [illegible] - lations and bait-coated dichlorvos are being evaluated at the U.S.D.A. Laboratory in Gainesville.

Prior to initiation of tests the following assumptions concerning the feasibility of the study were made:

1. No completely effective method is available for controlling fleas under field conditions.
2. Wild animals are repelled by many materials, making the use of insecticide in bait form limited by its attractiveness to the animal.
3. If an animal could obtain the toxic material internally, without having to feed on a treated bait it would be less repelled by the material.
4. Wild animals dislike any foreign matter on their feet or fur.
5. If a foreign substance is on the animal it will normally lick it off immediately.
6. If a rat could be lured through a sticky material that would adhere to the rat's feet or fur it would lick it off, thereby taking the substance internally.

Initial tests were run to evaluate the validity of the assumptions. Fenthion, found effective as a systemic for flea control on wild animals by Clark et al. (1971), was the insecticide of choice. Two materials, mineral [illegible] and vaseline, were chosen as potential carriers of

[illegible] lolds. [illegible]oth materials wer[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] repell[illegible] by [illegible] [illegible] grease [illegible] not the vaseline. The forme[illegible] not used after these first tests.

Fenthion at 1 and 3 percent mixtures in vaseline. produced no reduction in the fleas on the Rattus rattus in the tests. The 5 percent mixture gave 100 percent control throughout the week of testing.

These latter results were encouraging so tests simulating field conditions were tested next. When artificial rat runs were used and hooded rats were forced to pass back and forth through the run, less promising results were noted. To reduce the flea index 50 percent, the rat had to cross the 5 percent vaseline-fenthion mixture at least 3 times and 5 times for 100 percent control. It is felt that a method such as this is not practical unless the rat can pick up enough material on one run to kill the fleas present. Vaseline, although it didn't seem to have a repellent effect on the rats, was avoided after the rat got it on its feet the first time.

The last tests were a final attempt to see if any practical control could be expected from this approach. The results of the tests done in large, colony cages were not sucessful. R. rattus in the treated area had as many, or in some cases, more fleas than did the control cage. It is felt this method of control for fleas on

domestic rodents and/or wild rodents [illegible] not effective.

[illegible] Laboratory, for flea control by systemic and vapor action seem to have potential qualities to control fleas under field situations. These materials, like this one tested would be limited to small area control programs. They would not be practical for large scale operations to control fleas associated with epizootics that cover thousands of acres.

In the future, agencies responsible for flea control operations may have to rely on their knowledge of the ecological associations of plague as much as the use of insecticides in any form. If basic host-flea data such as presented in the field portion of this study were known in areas where plague epizootics occur, a brief survey done yearly, could potentially predict oncoming epizootics. Once these data were known, control methods such as previously discussed could be brought into these areas having small foci of plague and effectively control them before the epizootic spreads. This concept would require long-range ecological studies from a variety of flora and fauna associations in plague infected areas, but would require much less insecticide dispersal, and could possibly produce data that could eliminate plague from previously infected areas.

SUMMARY

Data was compiled on various aspects of host-flea relationships from 9 animal and 13 flea species collected from the study site at Red Bluff Ranch, New Mexico.

Animal data included: capture and recapture rates, relative abundance of the various animal species trapped, trapping efficiency of the National and Sherman live traps, and discussion of relationships such as host sex, and anal temperature to occurrence of plague epizootics.

Flea indices were presented graphically and in Table form by total indices and by indices of individual flea species. Advantages and disadvantages of both methods of data representation were given.

An evaluation of a potential method of controlling fleas on rodents with a fenthion-vaseline mixture in rat runs was made. The studies revealed this was not an effective method of controlling fleas on rodents. New and potential techniques of flea control in relation to plague epizootics were discussed and recommendations made.

APPENDIX I

Table 1. Mean anal temperatures of animals trapped on Red Bluff Ranch, New Mexico, March 13 through July 16, 1968.

Species[a]	TEMPERATURE °C						
	March	April	May	June	July	Max.	Min.
Dipodomys merriami	36.0[b] (14)	34.4 (57)	37.7 (88)	37.7 (82)	37.7 (23)	41.0	30.0
D. ordii	36.1 (11)	35.9 (48)	37.7 (79)	38.3 (47)	37.7 (17)	41.[illegible]	27.8
D. spectabilis	32.3 (2)	36.3 (15)	35.7 (28)	38.2 (21)	38.4 (11)	39.4	31.4
Neotoma micropus	35.1 (4)	35.6 (11)	37.1 (21)	37.1 (33)	37.7 (12)	38.6	34.4
Onychomys leucogaster	34.0 (1)	31.7 (3)	36.6 (7)	37.8 (1)	C	37.8	30.6
Peromyscus leucopus	28.6 (2)	33.8 (14)	36.1 (8)	36.9 (12)	C	39.7	[illegible]

Table 1. (Continued)

Species[a]	TEMPERATURE °C March	April	May	June	July	Max.	Min.
Spermophilus (Citellus) spilosoma	36.6 (1)	30.8 (4)	36.9 (26)	38.4 (10)	C	40.0	29.2
Sylvilagus audubonii	35.0 (1)	35.4 (6)	37.9 (6)	38.2 (5)	38.0 (7)	39.4	33.6

[a] Perognathus flavus was to small to use probe for anal temperatures.

[b] Number of animals used to determine mean anal temperatures.

[c] No animals of this species collected.

APPENDIX II

Table 1. Monthly indices of flea species on Dipodomys merriami, March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.

Flea species[a]	March	April	May	June	July
Meringis nidi	1.1	1.0	b	0.0	0.0
M. rectus	0.0	0.1	b	0.0	0.0
M. dipodomys	b	0.1	0.0	0.0	0.0
M. hilsingi	b	b	0.0	0.0	0.0
Echinophaga gallinacea	0.0	0.0	b	0.1	0.0
Thrassis bidis campestris	0.0	b	0.0	0.0	0.0
Anomiopsyllus novamexicanus	0.0	b	0.0	0.0	0.0
Orchopeas leucopus	0.0	0.0	0.0	0.0	0.0[1]
Number of hosts	25	31	96	89	28

[a] Flea species are listed in order of abundance on host animal.

[b] Less than 0.1 flea per host animal.

Table ". Monthly indices of flea species on Dipodomys ordii, March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.

Flea species[a]	March	April	May	June	July
Meringis nidi	0.9	0.8	0.0	0.0	0.0
M. rectus	0.1	0.0	0.0	0.0	0.0
M. bilsingi	b	0.0	0.0	0.0	0.0
Echinophaga gallinacea	0.0	0.0	b	0.0	b
Thrassis aridi campestris	0.0	0.0	b	0.0	0.0
Anomiopsyllus nevomexicanus	0.0	b	0.0	0.0	0.0
Number of hosts	16	28	83	50	23

[a]Flea species are listed in order of abundance on host animals.

[b]Less than 0.1 flea per host animal.

Table 3. Monthly indices of flea species on Dipodomys spectabilis, March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.

Flea species[a]	March	April	May	June	July
Meringis : _rectus_	7.0	8.8	2.3	0.5	0.1
_M._ nidi	10.8	3.3	0.0	0.0	0.0
_M._ dipodomys	0.2	0.3	0.0	0.0	0.0
_M._ bilsingi	0.2	0.2	0.0	0.0	0.0
Monopsyllus wagneri	0.0	0.2	b	0.0	0.0
Echinophaga gallinacea	0.0	0.0	b	0.1	0.0
Number of hosts	5	9	31	22	11

[a]Flea species are listed in order of abundance on host animals.

[b]Less than 0.1 flea per host animal.

Table 4. Monthly indices of flea species on Onychomys leucogaster, March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.

Flea species[a]	March	April	May	June	July
Echinophaga gallinacea	0.0	0.0	0.3	3.0	b
Orchopeas leucopus	0.0	0.0	0.9	0.0	b
Monopsyllus wagneri	2.0	0.0	0.0	0.0	b
Lecinges nidi	1.0	0.0	0.0	0.0	b
L. rectus	1.0	0.0	0.0	0.0	b
Thrassis fotus	0.0	1.0	0.0	0.0	b
Number of hosts	1	1	7	1	0

[a]Flea species are listed in order of abundance on host animals.

[b]No animals of this species collected during the month.

Table 5. Monthly indices of flea species on Perognathus flavus, March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.

Flea species [a]	March	April	May	June	July
Meringis dipodomys	0.0	0.5	0.0	0.0	0.0
M. nidi	0.0	0.5	b	0.0	0.0
Number of hosts	1	2	14	35	6

[a]Flea species are listed in order of abundance on host animals.

[b]Less than 0.1 flea per host animal.

Table 6. Monthly indices of flea species on Peromyscus leucopus, March 13 through July 16, 1968 at Red Bluff Ranch, New Mexico.

Flea Species[a]	March	April	May	June	July
Opisocrostis vagneri	3.0	2.5	1.6	2.1	b
Thrassis aridis arenestris	0.0	0.7	0.0	0.0	b
Aconiocerus novoreyicanus	0.2	0.0	0.0	0.0	b
Echinophaga gallinacea	0.0	0.0	0.0	0.1	b
Leptopsylla nidi	0.0	0.1	0.0	0.0	b
Number of hosts	5	6	20	7	0

[a] Flea species are listed in order of abundance on host animals.

[b] No animals of this species collected during the month.

Table 7. Monthly indices of flea species on Neotoma micropus, March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.

Flea species[a]	March	April	May	June	July
Echinophaga gallinacea	0.0	1.4	2.4	5.1	16.0
Orchopeas sexdentatus	6.0	12.8	4.0	1.8	2.2
Anomiopsyllus novomexicanus	4.4	8.6	2.1	0.3	4.5
Hoplopsyllus glacialis affinis	0.4	0.0	0.0	b	0.0
Monopsyllus wagneri	0.3	0.0	0.0	0.0	0.0
Leptopsylla nidi	0.3	0.0	0.0	0.0	0.0
Orchopeas leucopus	0.0	0.0	0.0	b	b
Meringis rectus	0.0	0.0	0.0	b	0.0
Thrassis fotus	0.0	0.0	0.0	b	0.0
Number of hosts	7	5	21	37	13

[a]Flea species are listed in order of abundance on host.

[b]Less than 0.1 flea per host animal.

Table 3. Monthly indices of flea species on Spermophilus (Citellus) spilosoma, March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.

Flea species[a]	March	April	May	June	July
Thrassis oridis campestris	0.0	b	0.8	0.0	0.5
T. fotus	3.0	b	0.6	0.0	1.5
Echinophaga gallinacea	0.0	b	c	0.0	0.0
Monopsyllus wagneri	0.0	b	c	0.0	0.0
Number of hosts	1	0	25	19	2

[a]Flea species are listed in order of abundance on host animals.

[b]No animals of this species collected during the month.

[c]Less than 0.1 flea per host animal.

Table 9. Monthly indices of flea species on Sylvilagus audubonii, March 13, through July 16, 1968 at Red Bluff Ranch, New Mexico.

Flea species[1]	March	April	May	June	July
Hoplopsyllus glacialis affinis	3.0	25.0	4.0	5.3	3.9
Echinophaga gallinacea	0.0	0.0	1.0	3.6	0.0
Orchopeas hexdentatus	0.0	0.0	0.0	0.2	0.0
Polygenus gwyni	0.5	0.0	0.0	0.0	0.0
Number of hosts	2	3	6	5	7

[1]Flea species are listed in order of abundance on host animals.

LITERATURE CITED

Adkins, J.D., W.L. Sorrell, and J.S. Imont. 1955. Systemic effect of selected chemicals on the bed bug and lone star tick when administered to rabbits. J. Econ. Entomol. 48:139-41.

Anthony, H.E. 1950. The capture and preservation of small mammals for study. Amer. Mus. Nat. Hist. Science Guide No. 61. N.Y. 38p.

Atlas of Plague. 1952. Amer. Geographical Soc. of N.Y., issued with geographical review. 42:4.

Bacot, A.W. 1914. A study of the bionomics of the common rat flea and other species associated with human habitations, with special reference to the influence of temperature and humidity at various periods of the life history of the insect. J. Hyg. Plague Suppl. III: 447-654.

Barnes, A.M. and L. Kartman. 1960. Control of plague vectors on diurnal rodents in the Sierra Nevada of California by use of insecticide bait-boxes. J. Hyg. 58:347-55.

Bennington, F. 1960. A systemic insecticide and bait for flea and rat control. J. Econ. Entomol. 53:160-20.

Blair, W.F. 1941. Techniques for the study of mammal populations. J. Mammal. 22:148-57.

Burden, G.S. 1966. Methods of detection of rat flea resistance to insecticides. World Health Organization. Seminar on rodents and rodent ectoparasites. 217:185-96.

Cummings, A.L. 1953. Sylvatic plague studies. Survival of rodents' fleas in the laboratory. Parasitology 43:329-34.

Hart, J.A. and L.F. Grossenheider. 1964. A Field Guide to the Mammals. The Riverside Press. Cambridge, Mass. 304p.

Buxton, P.A. 1946. Experiments with [illegible]. Parasitology 39:119-24.

Cavanaugh, D.C., J.D. Marshall, [illegible]. 1967. Plague in the Republic of Vietnam, 1965. Rsch. Team. Walter Reed Army Institute of Research. Vietnam, Ann. Prog. Rpt. Part V, Sec. IV. 495-511.

Clark, P.H. and M.M. Cole. 1968. Systemic insecticides for control of oriental rat fleas: Bait tests with hooded white rats. J. Econ. Entomol. 61:505-08.

Clark, P.H., M.M. Cole, D.L. Forcum, J.R. Wheeler, M.W. Weeks, and B.E. Miller. 1971. Preliminary evaluation of three systemic insecticides in baits for control of fleas of wild rats and rabbits. J. Econ. Entomol. 64:1190-93.

Cole, L.C. and J.A. Koepke. 1947. Problems in interpretation of the data of rodent-ectoparasite surveys and studies of rodent ectoparasites in Honolulu, T.H., Savannah, Ga. and Dothan Ala. Pub. Health Rep; Suppl. No. 202:1-71.

Cole, M.M., D.L. VanNatta, W. Ellerbe, and F. Washington. 1972. Rearing the oriental rat flea. J. Econ. Entomol. Scientific Note. In press.

DeMeillon, B. 1946. Effect on some blood-sucking arthropods of "Gammexane" when fed to a rabbit. Nature 148:639.

Drummond, R.O. 1958. Laboratory screening tests of systemic insecticides. J. Econ. Entomol. 51:425-27.

Eddy, C.W., W.S. McGregor, D.E. Hopkins, and J.L. Dreiss. 1954. Effects of some insects of blood and manure of cattle fed certain chlorinated hydrocarbon insecticides. J. Econ. Entomol. 47:35-58.

Eskey, C.R. and V.H. Haas. 1940. Plague in the western part of the United States. Trop. Geogr. Med. 22:257-75.

Haas, G.E. 1965. Temperature and humidity in the microhabitat of rodent fleas in Hawaiian cane fields. J. Med. Entomol. 2:313-16.

Hall, E.R. and K.R. Kelson. 1959. The mammals of North America. Ronald Press, N.Y. 1046p.

[illegible] 1960. Control of [illegible] [illegible]

[illegible] New York. 511p.

Hill, A. Jr., F.W. Knapp and H. Knutson. 1963. Laboratory studies with systemic insecticides for control of the oriental rat flea on white rats. J. Econ. Entomol. 56:302-04.

Hirst, L.F. 1923. On the transmission of plague by fleas of the genus Xenopsylla. Indian J. Med. Res. 10:789-820.

Hopkins, G.H. 1935. Some observations on the bionomics of fleas in East Africans Parasitology. 27:480-88.

Hopkins, G.H. and M. Rothschild. 1953. 1956. 1962. An illustrated catalogue of the Rothschild collection of fleas. Vol. 1. Tungidae to Pulicidae. Vol. 2. Vermipsyllidae to Xiphiopsyllidae. Vol. 3. Hystrichopsyllidae. Cambridge Univ. Press. Vol. 1: 361p; Vol. 2: 445p; Vol. 3: 560p.

Hubbard, C.A. 1947. The fleas of western North America. Iowa State College Press. 533p.

Hudson, B.W., M.I. Goldenberg, J.D. McCluskie, H.E. Larson, C.D. McGuire, A.M. Barnes, and J.D. Poland. 1971. Serological and bacteriological investigations of an outbreak of plague in an urban tree squirrel population. Amer. J. Trop. Med. Hyg. 20:255-63.

Jellison, W.L. 1959. Fleas and diseases. Ann. Rev. Entomol. 4:389-414.

Kartman, L. 1960. The role of rabbits in sylvatic plague epidemiology, with special attention to human cases in New Mexico and use of the fluorescent antibody technique for detection of Pasteurella pestis in field specimens. Zoonoses Res. 1:1-27.

Kartman, L. 1970. Historical and oecological observations on plague in the United States. Trop. Geogr. Med. 22:257-75.

Kartman, L., S.F. Quan, and H.E. Stark. 1967. Ecological studies of wild rodent plague in the San Francisco Bay area of California. Zoonoses Res. 1:99-119.

Kennerly, T.E. 1964. Microenvironmental conditions of the pocket gopher burrow. Texas J. Science 16:395-[illegible].

Knipling, E.F., R.C. Bushland, T.H. Baker, G.H. Culpepper, and E.S. Raun. 1948. Evaluation of selected insecticides and drugs as chemotherapeutic agents against external bloodsucking parasites. J. Parasitol. 34:55-70.

Krishnamarthy, B.S., S.N. Ray and G.C. Joshi. 1963. Note on technique used in rearing and maintaining a colony of the oriental rat-flea (Xenopsylla cheopis) World Health Organ. Working paper 63.19.

Lechleitner, R.R., J.V. Tileston, and L. Hartman. 1962. Die-off of a Gunnison's Prairie Dog Colony in Central Colorado. Zoonoses Rsch. 1:185-199.

Linkfield, R.L. 1966. Biological observations on the oriental rat flea, Xenopsylla cheopis (Rothschild), with special studies on the effects of the chemosterilant tris (1-Aziridinyl) phosphine oxide. Ph.D. Dissertation. Univ. of Florida. 100p.

Lindquist, A.W., E.F. Knipling, H.A. Jones, and A.H. Madden. 1944. Mortality of bed bugs on rabbits given oral doses of DDT and pyrethrum. J. Econ. Entomol. 56:128.

Macchiavello, A. 1950. Practical absolute rat-flea index used in plague control. World Health Organ. Tech. Rpt. Ser. No. 11:24-77.

Matheson, R. 1950. Medical Entomology. Comstock Pub. Co. Ithaca, N.Y. 612p.

McCoy, G.W. 1910. Bubonic plague in ground squirrels. N.Y. Med. J. 92:652-55.

Metcalf, C.L., W.P. Flint, and R.L. Metcalf. 1962. Destructive and Useful Insects. McGraw-Hill Book Co. Inc., N.Y. 1087p.

Meyer, K.F. 1942. The known and the unknown in plague. Amer. J. Trop. Med. Hyg. 22:9-36.

Miles, V.I., and M.J. Wilcomb, Jr. 1953. Control of native rodent fleas with DDT applied to stimulate aerial dusting. J. Econ. Entomol. 46:255-57.

Miller, A. H. and R.C. Stebbins. 1964. The Lives of Desert Animals in Joshua Tree National Monument. Univ. of Calif. Press. Berkeley and Los Angeles. 452p.

Miller, R.E., D.L. Forcum, K.W. Weeks, J.R. Wheeler, and C.D. Poel. 1970. An evaluation of insecticides for flea control on wild animals. J. Med. Entomol. 7:697-702.

Miller, G.S. and J.A. Rehn. 1901. Systematic results of the study of North American land Mammals to the close of the year 1900. Proc. Boston Soc. Nat. Hist. No. 1. 352p.

Mitchell, C.J. 1971. Relative abundance of rats and their ectoparasites in two grain warehouses in Calcutta, India, during 1964-1965. J. Med. Entomol. 9:56-61.
1971a. The microclimate of simulated burrows of *Bandicota bengalensis* (G & H) in Calcutta, India. (Rodentia: Muridae). Ibid. 8:307-11.

Mosby, H.S. 1963. Wildlife investigational techniques. Edwards Bros. Inc., Ann Arbor, Mich. 419p.

Parman, D.C., W.S. Abbott, J.J. Culvier, and W.V. Davidson. 1928. Ineffectiveness of internal medication of poultry for control of external parasites. U.S.D.A. Tech. Bull. 60.

Pollitzer, R. 1954. Plague. World Health Organ. Mono. Ser. No. 22. 698p.

Poel, C.D., D.L. Forcum, J.R. Wheeler and R.E. Miller. 1969. Wild animals and fleas of Red Bluff Ranch, New Mexico. J. Med. Entomol. 6:92-94.

Rust, J.H., Jr., D.C. Davis and H.E. Stark. 1970. *Pasteurella pestis* infection in humans. SEATO Med. Res. Lab. Clin. Res. Center, Bangkok Annual Prog. Rpt. p. 109.

Ryckman, R.E., C.T. Ames and C.C. Lindt. 1953. A comparison of aldrin, dieldrin, heptachlor and DDT for control of plague vectors in the California ground squirrel. J. Econ. Entomol. 46:598-601.
1954. Control of plague vectors on the California ground squirrel by burrow dusting with insecticides and the seasonal incidence of the fleas present. Ibid. 47:604-07.

[illegible]

[illegible]

Snodgrass, R.E. 1946. The skeletal anatomy of fleas (Siphonaptera). Smithsonian Misc. Coll. 104. No. 17. 89p. 21 plates.

Stark, H.E. 1959. The Siphonaptera of Utah. Dept. of Health, Education and Welfare, Public Health Service, Communicable Disease Center. Atlanta, Georgia. 231p.

Stark, H.E., D.W. Hudson, and B. Pittman. 1966. Plague Epidemiology. Ibid. 117p.

Stark, H.E. and V.I. Miles. 1962. Ecological studies on wild rodent plague in the San Francisco Bay area of California. Amer. J. Trop. Med. Hyg. 11:525-534.

Wheeler, J.R. 1968. Keys to the Siphonaptera of Red Bluff Ranch on Rodents, Rabbits, Hares and Carnivores. New Mexico, Environmental Improvement Agency, Vector Control Section. Misc. Pub. No. 2. 32p.

Wheeler, J.R., G.E. Haas, H.E. Stark, and D.E. Miller. 1971. The Fleas of New Mexico. In manuscript.

World Health Organization. 1966. Seminar on rodents and rodent ectoparasites. World Health Organ. Tech. Rpt. No. 217. 222 p.

Wu Lien-teh, W.H. Chun, R. Pollitzer, and Cy. Wu. 1936. Plague, a manual for medical and public health workers. Shanghai, Weishengshu Nat. Quar. Serv. 547p.

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Roy Edward Parsons was born on November 14, 1936, in Orlando, Florida. He received his elementary and secondary education in Orlando, Florida and graduated from U.T. Boone High School in Orlando in 1954. He received a B.S. degree with a major in entomology from the University of Florida in 1961. He obtained the M.S. degree with a major in entomology from Oklahoma State University in 1965.

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Roy Edward Parsons is married to the former Anna Lania [illegible] and is the father of two sons, Charles Gilbert, and [illegible] Christopher. He is a member of the Entomological Society of America, American Mosquito Control Association and Phi Sigma.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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June, 1972

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